"The Sharkiologist, giving over 400 million years of evolution a voice"

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Shark Senses

Smell, Sight, Taste, Hearing, Touch and Electroreception these are the six sensory systems sharks are equipped with allowing them to successfully exploit the environment they live in by locating prey, avoiding danger and finding a mate.

Different species of shark utilize these senses relative to the environment they live in, or the conditions they may encounter. For example bottom dwelling sharks such as the Angel shark which have their nostrils partially obstructed by the sea bed, would use its sense of smell less when locating prey than an open ocean dwelling shark such as the Oceanic Whitetip. Or if coastal shark species encounter poor visibility perhaps following a storm they would have to rely less on sight and more on their other senses.

Smell (Olfaction)

Sharks posses a pair of nostrils (also referred to as nares), just under the edge of their snout. The nares are completely separate from the mouth and throat and do not aid in respiration, instead they are used purely for olfaction. Each nare is divided into two channels by a nasal flap, the water enters one channel (incurrent aperture) gets passed over an area called the olfactory lamellae which contain neuro-sensory cells, these then send chemosensory information via the olfactory bulb to the large olfactory lobe in the sharks forebrain. The olfactory lamellae are a series of folds on the surface of the olfactory sac; these folds increase the surface area and provide the shark with a greater opportunity of detecting smells. After passing through the olfactory sac the water is then channelled out through the excurrent aperture.

If the shark detects a smell which it wants to investigate (odour from prey or pheromones from a potential mate), it will swim in the direction of the scent moving its head back and forth (similar to its natural swimming motion), this motion will allow it to detect the direction of the smell by following the most concentrated signal. These movements can become exaggerated into larger "S" shapes if the shark loses the signal or if the signal is too wide to use for accurate navigation.

View of the nares on the underside of the snout of a lesser spotted dogfish (Scyliorhinus canicula).

A simplified view of the shark's brain (PDF)

Sight

In the majority of shark species the eyes are well developed, complex structures containing rod (highly sensitive to light intensity) and in some species cone cells (may allow sharks to see colour). They can control the amount of light entering the eye by dilating or contracting their pupils. Focussing is controlled by the rectus muscles, these pull the lens closer to or further away from the retina, when used in conjunction with the oblique muscles movement of the entire eye is achieved.

"**The Sharkiologist**
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Most sharks possess excellent vision in dim light conditions; this is due to the retina containing millions of rod cells together with a structure called the tapetum lucidum, this is a layer found behind the retina which reflects light back onto the retina amplifying the image. The tapetum lucidum has another function, in bright light pigmented cells cover the tapetum reducing reflections and protecting the retina.

Sharks possess an upper and lower eyelid but these usually do not meet and therefore do not provide a full cover for the eye. Some sharks such as the tiger shark (Galeocerdo cuvier) have a "third eyelid" known as the nictitating membrane, this rolls up from the base of the eye to completely cover the eyeball, the use of this nicitating membrane is demonstrated regularly in shark documentaries, and most notably when the shark is attacking its prey. Species like the white shark (Carcharodon carcharias) which do not have the nicitating membrane often employ a different strategy to safeguard the eye; they roll the eye into the back of the socket exposing a hardened pad at the rear of the eyeball. The existence of such strategies designed to protect the eye, highlight the importance of sight as a sensory function to the shark.

Some sharks such as the blue shark (Prionace glauca) have a light sensitive "third eye". Indicated by a lighter coloured spot called the pineal window on the top of the sharks head directly above the pineal gland, although speculative it is suggested that the shark may use this to aid navigation.

A diagram of a shark's eye including key structures (PDF)

Taste (Gustation)

As a shark bites into an object (prey or otherwise), chemicals are released and attach themselves to gustatory sensory cells present in the sharks mouth and throat, these gustatory cells then send messages to structures (the thalamus and the hypothalamus) located in the sharks forebrain. The shark will then either accept or reject the object it has bitten.

A note on shark attacks

Taste is often discussed in the context of shark attacks on humans. The entire consumption of a human by a shark is very rare, most attacks are comprised of a single bite which (depending on the location of the bite) are usually non fatal. The question is why do sharks bite and release humans? There are a couple of possibilities:

i) the chemicals detected do not trigger an acceptance signal – perhaps a much higher fat/blubber content is required, or the interpreted signals are too different from their usual prey source;

ii) the shark is employing an energy saving tactic of inflicting a potentially fatal wound, allowing the prey to tire and then intending to finish the meal.

This latter possibility is difficult to verify due to the circumstances of most sharks attacks, for example in the majority of instances the shark has been reported to swim away following the first bite, but why is this? The victim is rarely alone in these situations with fellow ocean goers on hand to help the victim get out of the water; hence it is not always clear if the shark would hang around in the absence of commotion caused by other people.

The reasons why shark attacks occur is also a hotly debated issue with various suggestions; mistaken identity – surfers looking like seals (although sharks have reasonably well adapted eyesight, studies on the white shark Carcharodon carcharias, have shown that when towing a seal cut-out behind a boat some sharks will still attack), poor water visibility, curiosity, shark dependent (some sharks are more curious/energetic/aggressive/excitable than others), ill/weak sharks (if a shark is sick or hasn't eaten for a long time perhaps any prey is better than none). All of these suggestions may play some part in why attacks happen. It is important to remember however that by going in the water you are becoming a part of the sharks' environment and it is important to respect that, the shark is a top predator; you wouldn't for example enter a lion enclosure without a little caution!

Hearing (balance and pressure detection)

The shark ear is located in the frontal skull (chrondocranium) and is completely internal with only a tiny opening on the sharks' head - not the spiracle which is involved in respiration. The ear detects sound with frequencies ranging from <20 to about 800 Hertz, most sharks show an attraction to infrasound (<20Hz) this is most likely due to the low frequency sounds emitted by struggling prey. The shark ear is also used for balance/orientation (by utilising the fluid filled semi-circular canals, with the movement of the fluid activating sensory hair cells) and pressure detection (by direct activation of the hair cells within the canals allowing sensory signals to be relayed to the brain via the auditory nerve).

The shark ear consists of a pair of membranous labyrinths with three fluid filled semicircular canals and four sensory maculae each. The saccule, lagena, and utricle are sensory areas that are thought to be involved in both balance and sound perception. They consist of a patch of sensory hair cells on an epithelium overlain by an otaconial mass. The otoconia, made of calcium carbonate granules act as an inertial mass. As in some teleost fish, these otolith organs are thought to be responsive to accelerations produced by a sound field, which accelerate the shark and the sensory macula relative to the otoconial mass. Some sharks, such as the spiny dogfish (Squalus acanthias), have been found to incorporate sand grains as a way to increase the otoconial mass.

Sharks are unique among fishes in having a tympanic connection, the fenestra ovalis, to the posterior semicircular canal which enhances their hearing. Sound and balance information is transmitted via the auditory nerve to an area in the medulla and then onto a higher-order midbrain audiotory center followed by the dencephalon and in some species the tencephalon auditory areas.

Anatomy of the ear of an elasmobranch (PDF)

Touch

A shark can feel a certain amount of direct contact due to free nerve endings embedded in the skin, mouth, jaws and even teeth. They can also sense things internally due to the presence of proprioceptors (microscopic sensory cells) found throughout the muscles, joints, digestive system and blood vessels. Sharks have a heightened sense of indirect touch via water displacement around the sharks' body, this is accomplished by the movement of sensory hair cells which are present in the neuromasts that make up the lateral line system. This system is comprised of a series of canals or channels usually visible to the naked eye as a series of pores or lines, these run from the head all the way to the upper lobe of the tail.

This ability to detect water displacement aids the shark in prey detection and increases its awareness of any moving object in the water column. As a fish swims near a shark it will displace water and send waves outwards, these waves then directly move the cupula (a jelly like substance covering the cells) which bend and activate the sensory hair cells inside that send a signal to the medulla oblongata in the brain. The shark will also obtain an orientation on the prey item/object based on the strength of the signal received by the lateral line canals.

It is worth noting that the lateral line is also used to detect odour through a process referred to as "eddy chemo-taxis" meaning the tracking of odour and turbulence simultaneously.

Diagram showing the main lateral line canals on the conventional shark shape (PDF)

Electroreception

The Ampullae of Lorenzini are specialised pores that are thought to have evolved from the lateral line system. They consist of a small chamber (the ampulla) and a sub-dermal canal which projects outward to the surface of the skin, the ampulla contains hundreds of sensory hair cells. The wall of the canal contains a double layer of connective tissue fibres and epithelial cells, which are tightly joined together to form a high electrical resistance between the inner and outer wall of the canal. The canal and ampulla themselves are filled with a high potassium low resistance gel that forms an electrical core conductor with a resistance equalling that of seawater.

Fish carry an electrical charge different to that of seawater and so a weak voltage is created (by the movement of positive and negative particles moving back and forth shifting electrons in an attempt to become stable). Because the salt in the water contains both sodium and chlorine ions which can move freely in the water the electricity itself is transported, and this is what the ampullae of lorenzini is able to detect.

The signals from the ampullae of lorenzini are transmitted via the VIIIth cranial nerve to the electrosensory processing areas in the brain (the thalamus and the forebrain).

The presence of blood in the water will intensify the electrical current due to the salt content of the blood.

Ampullae of Lorenzini around the mouth of the lesser spotted dogfish, with a diagram detailing the structure of the pore (PDF)